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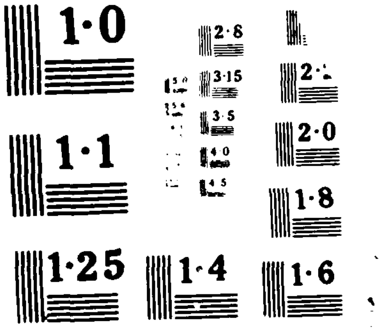
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Final Report
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ONR Contract No. N00014-84-K-0349

with

The Electromagnetics Laboratory
University of Colorado
Boulder, CO 80309

David C. Chang and Edward F. Kuester
Co-Principal Investigators

Covering the contract period from
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Abstract

A summary of the work performed under ONR contract N00014-84-K-0349 is presented. Results include advances in theory and design of microstrip patch antennas, development of a bivariational method to analyze antennas and open transmission lines, analysis of microstrip structures as waveguides and resonators, and a study of the effects of cover layers on microstrip antennas.

Introduction

In this project, we have investigated radiating and guiding structures in microstrip. Discontinuities have been approached using a bivariational method, which allows us to obtain reasonably simple expressions for junction scattering parameters which are nonetheless more accurate for a given approximate current distribution than predicted directly by that trial current function. Refinement of the edge-admittance model for wide patch antennas of arbitrary shape has considerably improved the magnetic edge current method for these structures, without the need for extensive numerical calculations. The two-dimensional analysis method has been applied to a variety of practical structures as the modelling in this method is refined by inclusion of more mutual impedance effects between different parts of the edge. Finally, effects of a cover-layer and substrate curvature on the performance of patch antennas has been studied, with a view to understanding their behavior in real-world conditions.

Publications Under the Contract

A. Bivariational methods for open waveguide discontinuity modeling

*1. E.F. Kuester and D.C. Chang, "A unified approach to the derivation of bivariational principles in acoustics and electromagnetics", Scientific Report No. 80, Electromagnetics Laboratory, University of Colorado, August 1986.

2. D.C. Chang and Raj Mittra, "Techniques for solving open-waveguide discontinuity problems," **Abstracts**, XXIst General Assembly URSI, Florence, Italy, Aug 28-Sept 5, 1984, p. 53.

3. D.C. Chang, "Double variational formulation of a stripline Y-junction," **Abstracts**, National Radio Science Meeting, Boston, MA, June 25-29 1984, p. 132.

*4. David C. Chang and Nancy A. Kuester, "A computer-aided-design approach to thin-wire, linear antennas and arrays," **Abstracts**, 1984 International Symposium on Antennas and Propagation, Boston, MA, June 25-29, 1984, Vol. 1, p. 445.

*5. N.A. Kuester, "Double variational evaluation of linear antenna current," (M.S. Thesis), Scientific Report No. 79, Electromagnetics Laboratory, University of Colorado, Boulder, 1985.

*6. E.F. Kuester and D.C. Chang, "A general formulation for open waveguide reflections without using the complete mode spectrum," 1985 North American Radio Science Meeting, Vancouver, Canada, p. 212.

Schwinger, Rumsey and Vainshtein, more than 25 years ago, used what might be called bivariational methods to solve scattering problems for antennas and scatterers in free space or in hollow metallic waveguides. These functionals may involve two distinct trial functions, and are independently stationary about their correct values with respect to variations in each one. We have derived new bivariational expressions for scattering caused by **modification** of a metallic or dielectric object. This permits the study of scattering by discontinuities in open waveguiding structures, especially when the complete modal spectrum is cumbersome to compute (e.g., for microstrip and other planar lines). The method can yield relatively simple but accurate expressions which are useful in computer-aided design of waveguide/antenna elements.

*** Indicates work partially supported by ONR.**

Applications have been made specifically to several problems. The stripline Y-junction has traditionally been treated using basic transmission-line analysis. We have obtained corrections to this zero-order model using the bivariational method, which accounts for spurious radiation and dynamic junction reactances. The expression for the scattering matrix in fact is in closed form, involving only exponential integrals and elementary functions

The bivariational approach has also been applied to the determination of reflection coefficients at unevenly terminated 2- or 3- wire transmission lines. These values are then used in a resonance expression to find the input impedance and current distributions on 1-, 2- and 3- wire linear antenna arrays. The results are seen to compare well with those from other approaches found in the literature.

B. Input impedance of a probe-fed microstrip patch antenna

7. J. Venkataraman and D.C. Chang, "Input impedance to a probe-fed rectangular microstrip patch antenna," **Electromagnetics**, Vol. 3, nos. 3-4, July-Dec. 1983, pp. 387-399.

An improved theory for the input impedance of a probe-fed microstrip patch antenna has been developed. The natural modes are established from a transverse resonance condition which incorporates the angularly dependent reflection coefficients and a dynamic wall susceptance associated with the patch boundaries. The input reactance is shown to be largely associated with the evanescent waves present due to the excitation of the mode at resonance. Analytical results are presented to describe the input impedance of a rectangular patch antenna as a function of its dimensions, substrate thickness and dielectric constant, probe dimension and location, and the frequency.

C. Geometrical theory of a microstrip patch resonator

8. D.C. Chang, E.F. Kuester and A.R. Mahnad, "Geometrical theory of a one-dimensional microstrip resonator: The effects of top-side charges and currents," **Radio Science,** Vol. 20, pp. 819-826 (1985).

Resonances of a one-dimensional microstrip patch structure were determined based upon reflections of waves from the patch edges. The new theory includes the effect of currents which have penetrated to the top side of the patch from underneath, and modify the resonant frequency and Q-factor of the resonator. An unexpected result was that these currents can under some conditions actually make the Q-factor <u>higher</u> than is predicted by the theory which ignores top-side effects.

D. Refined edge-slot model for arbitrary microstrip patches

9. E.F. Kuester, D.C. Chang and T.M. Martinson, "A note on the edge admittance of a wide microstrip patch with electrically thin substrate," Scientific Report No. 81, Electromagnetics Laboratory, University of Colorado, March, 1986.

10. E.F. Kuester, "Explicit approximations for the static capacitance of a microstrip patch of arbitrary shape, " Scientific Report No. 82, Electromagnetics Laboratory, University of Colorado, March, 1986.

11. T.M. Martinson and E.F. Kuester, "The edge admittance of a wide microstrip patch as seen by an obliquely incident wave," Scientific Report No. 87, Electromagnetics Laboratory, University of Colorado, January 1987.

12. E.F. Kuester, D.C. Chang and T.M. Martinson, "Refinement of the radiating-slot model for microstrip antennas to account for near-field phenomena," 1985 North American Radio Science Meeting, Vancouver, Canada, p. 92.

13. E.F. Kuester, "Static capacitance of a large microstrip patch of arbitrary shape," National Radio Science Meeting, 13-16 January 1986, Boulder, Colorado, p. 10.

14. E.F. Kuester and T.M. Martinson, "Determination of resonant modes for an arbitrary microstrip patch on an electrically thin substrate", National Radio Science Meeting, 13-16 January 1986, Boulder, Colorado, p. 224.

The "equivalent radiating slot" model for microstrip antennas represents the fields above the antenna by equivalent magnetic line currents at the edges of the patch. We have been able to refine this model for electrically thin substrates by using the known exact static field distributed near the edge in order to correctly predict dynamic edge effects in actual patch problems.

The correct low-frequency limiting behavior of a plane wave reflected from the edge of a patch conductor is produced in this way. Further, we have been able to derive an explicit expression for the fringe field correction of the static capacitance of an arbitrarily-shaped patch. This led us to use the same concept in deriving a generalized boundary condition for the voltage at the edge of an arbitrary patch under dynamic (resonant or nonresonant) conditions. We find that commonly assumed edge extensions are not sufficient to describe these edge effects accurately, nor even mutual impedance effects due to coupling over the top of the patch. Comparison with careful experimental data has produced consistent and close agreement of resonant frequency, Q and input impedance to less than 1% accuracy.

E. Capacitance of small microstrip patches

15. E.F. Kuester, "Static capacitance of a small microstrip patch of arbitrary shape,"1986, National Radio Science Meeting, Philadelphia, p. 176 (see also publication no. 10 above).

A complementary approach to the static capacitance problem suitable for microstrip patches small compared to substrate thickness is presented. Together with the results for large patches, we are able with analytical formulas to reproduce the capacitance of any shape and size of microstrip at better than

10% accuracy. This will provide useful design information in microstrip circuits without the need for numerically intensive procedures.

F. Effects of a cover layer and substrate curvature on microstrip patch antennas

16. Y. Tu, K.C. Gupta and D.C. Chang, "Edge admittance for microstrip antennas with a dielectric cover layer," **Abstracts**, National Radio Science Meeting (URSI), Boulder, Colorado, January 1986, Digest p. 227.

*17. Ahmad Hoorfar, K.C. Gupta, D.C. Chang, "The effects of cover-layer on radiation and surface-waves of a microstrip patch antenna," National Radio Science Meeting, January 1986, Boulder, Colorado, Digest p. 232.

*18. Ahmad Hoorfar, K.C. Gupta and D.C. Chang, "Effects of cover layer on radiation and surface-waves of a microstrip patch antenna," Scientific Rept. No. 88, Electromagnetics Laboratory, University of Colorado, Boulder, Colorado, September 1986.

*19. Ahmad Hoorfar, K.C. Gupta and D.C. Chang, "Effects of cylindrical-curvature on radiation pattern of a microstrip antenna with a cover-layer," National Radio Science Meeting Digest, January 1986, p.233.

A Wiener-Hopf formulation has been worked out for finding edge admittances of rectangular microstrip patches with a lossless dielectric cover layer. Numerical code for the calculation of the reflection coefficient is in place, and the results are directly applicable to the design of microstrip antennas with a cover layer.

The effects of radiation and surface waves in the presence of such a cover layer have also been assessed. When the substrate is curved into a cylindrical shape, there can be substantial resonant interference effects from such waves circulating around the cylinder and re-encountering the patch. Effects on the side-lobe levels of such antennas are discussed.

G. Two-Dimensional analysis of microstrip structures

20. G. Kumar and K.C. Gupta, "Broadband microstrip antennas using additional resonators gap-coupled to radiating edges", **IEEE Trans. on Antenna and Propagation,** Vol. AP-32, Dec. 1984, pp. 1375-1379.

21. K.C. Gupta, "Recent advances in microstrip antennas." **Microwave Journal**, vol. 27, Oct. 1984, pp. 50-67.

22. P.C. Sharma and K.C. Gupta, "An alternative procedure for implementing desegmentation method," **IEEE Transactions Microwave Theory Tech.,** Vol. MTT-32, January 1984, pp. 1-4.

23. K.C. Gupta, "On the solution of two-dimensional field problems with complex impedance boundaries," **Abstracts**, URSI National Radio Science Meeting, Boulder, Colorado, January 1984, p. 14 (Paper B3-1).

24. K.C. Gupta, "CAD oriented microstrip discontinuities characterization," an invited paper for special session on CAD oriented field and network analysis at IEEE Symposium on Antenna and Propagation and National URSI Meeting, Boston, MA, June 1984, **Abstracts**, p. 64 (Paper URSI/B-6-4).

25. K.C. Gupta, "Two-port transmission characteristics of rectangular microstrip patch antenna," IEEE AP-S International Symposium Digest 1985, Vancouver BC, pp. 71-74, June 1985.

26. M. Abouzahra and K.C. Gupta, "Analysis and design of five-port circular disc structures for six-port analyzers," 1985 IEEE MTT-S International Microwave Symposium Digest, pp. 449-452.

A wide variety of antenna and transmission-line junction problems in microstrip has been addressed using two-dimensional analysis techniques. This analysis technique is based on planar waveguide models of microstrip and stripline circuits. The procedure employs two-dimensional Green's functions for segments of various geometrical shapes and segmentation methods to obtain the circuit characterization. Studies have dealt with the following problems: (i) Two-port S-parameter characterization of rectangular microstrip resonators. Analytical expressions for z-parameters have been derived for operation near the resonance frequency of the dominant mode. Results are applicable to design of series-fed linear microstrip arrays and also for rectangular microstrip patches used in filter or biasing circuits, (ii) A symmetric five-port circular microstrip disc structure has been analyzed for possible application in a six-port network, analyzer system. The approach is useful in characterization and design of similar circuit configurations, (iii) General aspects of the segmentation and desegmentation methods have also been studied.

Personnel Supported Under the Contract

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